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Abstract

The carrier frequency of the presented Radio Over Fiber downlink at 32 GHz is generated by stimulated Brillouin scattering and an error free 1 Gbit/s data transmission is realized.

Introduction

The growing demand for wireless gigabit networks has strongly affected the research interests of new transmission systems. Recently, a 10 Gbit/s wireless transmission link at 125 GHz verified the great potential of Millimeter wave (mm-Wave) photonics [1]. Several optical generation techniques of mm-waves have been verified in the past. Most of them are based on the heterodyning of two phase correlated frequency components in a photo detector. Besides a high level of complexity and sensitivity to environmental influences, a required high frequency microwave synthesizer, limits these techniques. However, the application of stimulated Brillouin scattering (SBS) as a narrow band amplifier offered new opportunities in the field of mm-Wave generation [2, 3]. SBS occurs even at low power levels and has low phase noise properties [4, 5]. On the other hand, the gain bandwidth lies in the range of tens of MHz for Standard Single Mode Fibers (SSMF) and limits its applicability [6].

In this paper a simple mm-Wave generation method and the implementation of a modulation set-up for Radio Over Fiber systems (ROF) is presented. The technique requires neither a synthesizer higher than 6.4 GHz nor unconventional optical components. For modulation processes it is independent of the SBS gain bandwidth. The method is based on the superposition between the modulated carrier and a sideband that is amplified by SBS.

Experiment

The light beam of a narrowband fiber laser (FL; wave length: 1.55 µm; line width < 1 kHz is separated into two paths according to Fig. 1. In the upper path the light is intensity modulated by a Mach Zehnder Modulator (MZM1) that is driven by a 6.4 GHz sinusoidal signal. Since the MZM is driven in the nonlinear regime, a flexible frequency comb with a component separation of 6.4 GHz is generated.

The light in the lower path is modulated by a data stream by a further MZM (MZM2). The MZM is driven by a 1 Gbit/s pseudo random bit sequence with a pattern length of $1 \cdot 10^{23} - 1$ (PRBS23). The idea of modulating the optical carrier and hence the modulation of the mm-Wave was given by Park [8]. The modulated and amplified optical carrier and the frequency comb are injected into a 50.45 km long
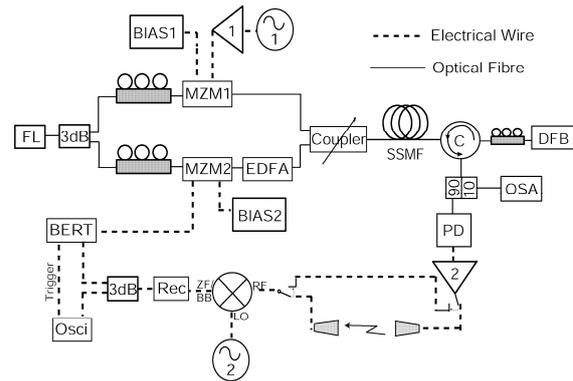

Fig. 2. Experimental set up of the Radio Over Fiber system. FL: Fiber Laser; MZM: Mach-Zehnder Modulator; EDFA: Erbium Doped Fiber Amplifier; BERT: Bit Error Rate Tester; DFB: Distributed Feedback Laser Diode; PD: Photo Detector; OSA: Optical Spectrum Analyzer; REC: Receiver Unit; SSMF: Standard Single Mode Fiber; C: Optical Circulator.

SSMF via a tunable coupler. The fiber acts as a transmission and amplification medium at the same time. From the opposite site a pump wave is injected into the same fiber. The pump source is a conventional Distributed Feedback laser diode (DFB) that emits a cw signal with a 3 dB bandwidth of 3 MHz. The power is adjusted to be 4.1 mW at the output of the optical circulator. This is done in order to operate the system well below the Brillouin threshold.

The pump wave generates a Brillouin gain spectrum with a measured bandwidth of 28 MHz. The frequency of the pump wave is adjusted in such a manner that the frequency of the gain fits exactly to the frequency of the component that should be amplified. This is one of the sidebands of the frequency comb. For the SBS amplified sideband of the 5th order, a gain of 32.31 dB was measured. The modulated carrier and the amplified sideband are coupled out via a circulator and heterodyned in a photo detector (PD). All undesired sidebands are attenuated due to the natural loss of the fiber. A power adjustment of the sideband and the carrier is achieved by the application of the tunable coupler. The desired frequency components have a separation that corresponds to five (5th sideband) multiplied with

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the modulation frequency (6.4 GHz). The two amplified sidebands with a frequency separation of 32 GHz at the circulator output can be seen in Fig. 2. The millimeter wave signal is generated by the superposition (heterodyning) of both components in
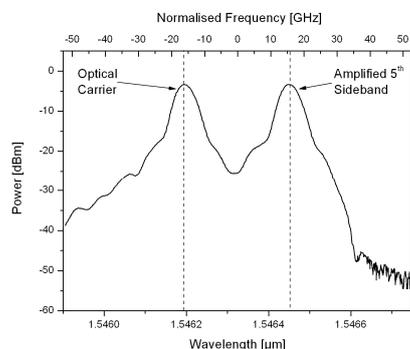

Fig. 2. Optical spectrum at the circulator output.

the PD. A broadband RF amplifier (amplifier 2 in Fig. 2) enhances the signal to about -10 dBm. In order to simulate a ROF downlink, the data signal at 32 GHz is down converted by an external mixer with a LO of 16 GHz. A receiver unit that acts as a base band amplifier enhances the signal in order to analyze it with an oscilloscope.

Results

An investigation of the carrier signal at 32 GHz showed a high performance in respect to the line width and the stability. Thus a full width at half maximum (FWHM) bandwidth of 300 Hz was measured. Since the electrical spectrum analyzer has a resolution of 300 Hz, we assume that the actual bandwidth is lower. Phase noise measurements at 49 GHz using a comparable set-up showed a noise of -95 dBc/Hz at 10 kHz offset from the carrier. It can be assumed that the phase noise of the carrier discussed in this paper lies in the same range.

After a successful down conversion into the baseband the received error free signal was analyzed with an
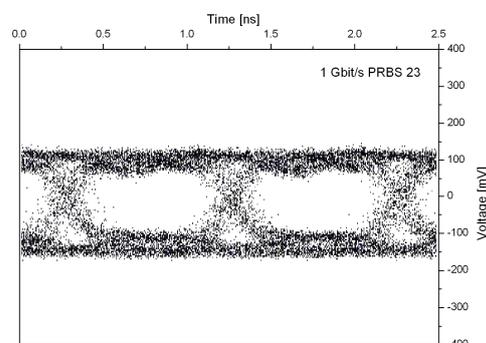

Fig. 3. Eye diagram of the 1 Gbit/s PRBS 23 signal back to back measured at the oscilloscope.at the circulator output.

eye diagram shown in Fig. 3. As can be seen for the back to back case, the eye of the 1 Gbit/s signal is clearly opened without any significant distortions. The calculated Q-factor was 6.2 which corresponds to a bit error rate (BER) of $287 \cdot 10^{-12}$.

A radio propagation of the 1 Gbit/s signal at 32 GHz between two horn antennas has been successfully realized. On the other hand, the signal power decreased and the eye got closed due to the increased path loss. Therefore, further investigations were limited due to the insufficient equipment (RF amplifier) of our laboratory.

Conclusion

In this paper a simple method for the generation of mm-Waves for Radio Over Fiber downlink systems was proposed. It is based on the modulation of the optical carrier with data. The heterodyne superposition with a SBS amplified sideband generates a high quality carrier signal at 32 GHz with a line width of less than 300 Hz and a phase noise of around -95 dBc/Hz @ 10 kHz offset from the carrier. An error free data transmission of a 1 Gbit/s PRBS 23 signal over a 50.45 km long SSMF was successfully completed and radio propagation between two antennas was shown. Since the carrier is modulated, the data rate is not restricted by the Brillouin bandwidth. At the same time very high carrier frequencies can be generated since alternative comb generation techniques like phase modulation of four wave mixing can be introduced in the system. Hence, very high data rates at high carrier frequencies are possible with the presented set-up.

Acknowledgement

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